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DESIGN AND APPLICATION OF AN UNDERWATER ACOUSTIC PARAMETRIC SOURCE

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Monterey, California

THESIS

DESIGN AND APPLICATION OF AN
UNDERWATER ACOUSTIC PARAMETRIC SOURCE

by

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Thesis Advisor: A. I. Eller

December 1973

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by

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requirements for the degree of

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ABSTRACT

Parametric sound generation has been an active area of applied research for the last ten years. The acoustic parametric source takes advantage of the non-linearity of the medium to generate energy at the difference of two high frequencies. The principal advantage of a parametric source over a conventional transducer is its high resolution capability. The characteristic is a result of its narrow beam width (with no attendant side lobes) and broad bandwidth.

The parametric source was designed and tested in the laboratory and also at sea. Laboratory studies showed severe broadening of the parametric beam and reduction of difference-tone pressure on reflection from a smooth air-water surface. This is attributed to the phase reversal that occurs on reflection.

The coefficient of amplitude variation at sea was found to be less than 3% at the depth of 20 and 40 ft. and was much higher at 10 ft. depth. The coefficient of amplitude variation was higher for the parametric beam as compared to that of a conventional sound beam at the depths of 20 and 40 ft. The parametric beam had lower coefficient of variation as compared to that of a conventional beam at the depth of 10 ft.

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LIST OF ILLUSTRATIONS

LIST OF SYMBOLS/ABBREVIATIONS USED

r	...	distance between transducer and hydrophone.
a	...	lateral distance of hydrophone perpendicular to the acoustic axis of the transducer.
d	...	depth of the transducer or hydrophone from the surface of water.
fm	...	modulating frequency.
fr	...	primary frequency.
G	...	gain in the receiver circuit.
Irms	...	RMS current input to the transducer.
Vpp	...	peak to peak voltage of the signal received by the hydrophone.
BW	...	pass band filter setting band width in the receiver circuit.
E-8	...	USRD type E-8 transducer used as a parametric source.
F-33	...	transducer type F-33 used as a conventional sound source.
LC32	...	hydrophone model LC32 used as a receiver.
θ	...	Angle of inclination of transducer from its acoustic axis. (i.e. when parallel to the surface of water).
SPL	...	sound pressure level reference one microbar.
VL	...	Voltage Level = $20 \log \frac{V_{rms}}{1 \text{ volt}}$

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I. INTRODUCTION

An acoustic parametric beam transmission and receiver system was designed using a USRD type E-8 transducer as a parametric source. An LC-32 was used as the receiving hydrophones.

This study has been divided into four sections. The first section deals with the design and evaluation of the optimum parameters of this acoustic parametric system. It also deals with the free field measurement of the radiation pattern of the parametric beam. The absence of the side lobes in the parametric beam was established.

The second section deals with the surface reflection of the parametric beam from a water-air surface. The broadening of the beam and the reduction in sound pressure levels were observed after the reflection of the beam.

The third section deals with the shipboard use of this acoustic parametric system. The frequency response of the system was observed at sea. The coefficient of variation for various depths of transducer in sea water was also calculated.

The fourth section deals with the summary of the study carried out in the first three sections.

The system designed was flexible enough to operate for secondary frequencies above 40 KHZ. It was, however, not adequate for secondary frequencies less than 40 KHZ.

II. DESIGN AND OPERATION CHARACTERISTICS OF THE ACOUSTIC PARAMETRIC SOURCE

A. DESCRIPTION OF EQUIPMENT

A block diagram of the transmitting and receiving systems is shown in Fig. 1.

1. Transmitting System

A signal oscillator provides the basic frequency of modulation. The output of this oscillator is connected to the "VCA IN" terminals of the Wavetek. The Wavetek model 136 is used as a modulator and an attenuator. The carrier frequency for modulation is about 1.4 MHZ, which corresponds to the resonance frequency of the E-8 transducer. The optimum mode of modulation is using Wavetek as an amplitude modulator as will be shown later in the discussion. The signal output of the Wavetek (modulator) next passes through a signal gate i.e. "Tone Burst Generator" GR1396A. The gated signal is next amplified by a power amplifier GR 1233-A. The signal output of the power amplifier is passed through a high pass filter, which blocks the slight amount of difference frequency current that is generated within the amplifier. The filter is a 'T' network consisting of two 0.0033μf capacitors and a 3.5 μH inductor to the ground. The driving signal is then taken to USRD type E-8 transducer serial NO. 29.

The r.m.s. amplitude of the driving current is measured by means of a Pearson Electronics current transformer looped

about one wire leading to the transducer. The current transformer produces a voltage, proportional to the current, that is measured with a HEWLETT PACKARD 3400 r.m.s. Voltmeter during CW operation.

2. Receiving System

LC32 is used as the receiving hydrophone which is connected to a pre-amplifier, HEWLETT PACKARD 466A. The signal is then passed through a Band Pass Filter, KROHNHITE 3322. The output of the B.P. filter is taken to the input terminals of an amplifier, HP466A. The output of HP466A is then taken to the oscilloscope, which measures the peak to peak voltage of the incoming signal.

The unfiltered signal is also taken to the oscilloscope as shown in Fig. 1.

The frequency pass band of the KROHNHITE 3322 B.P. filter is adjustable from .001HZ to 99.9KHZ.

The receiving voltage sensitivity of the LC32 hydrophone was calibrated by placing it in the free field of a calibrated USRD type F33 transducer, used as a standard source. The sensitivity was found to be -112.6 db reference one volt per microbar, at 50 KHZ.

B. SYSTEM RESPONSE FOR MODULATION SCHEMES

Two modes of modulation were available i.e. (i) amplitude modulation and (ii) suppressed carrier modulation. The purpose of this experiment was to find the mode of modulation which is more suitable to the system. The two characteristics showing the response of the system with the mode of modulation are as in Fig. 2.

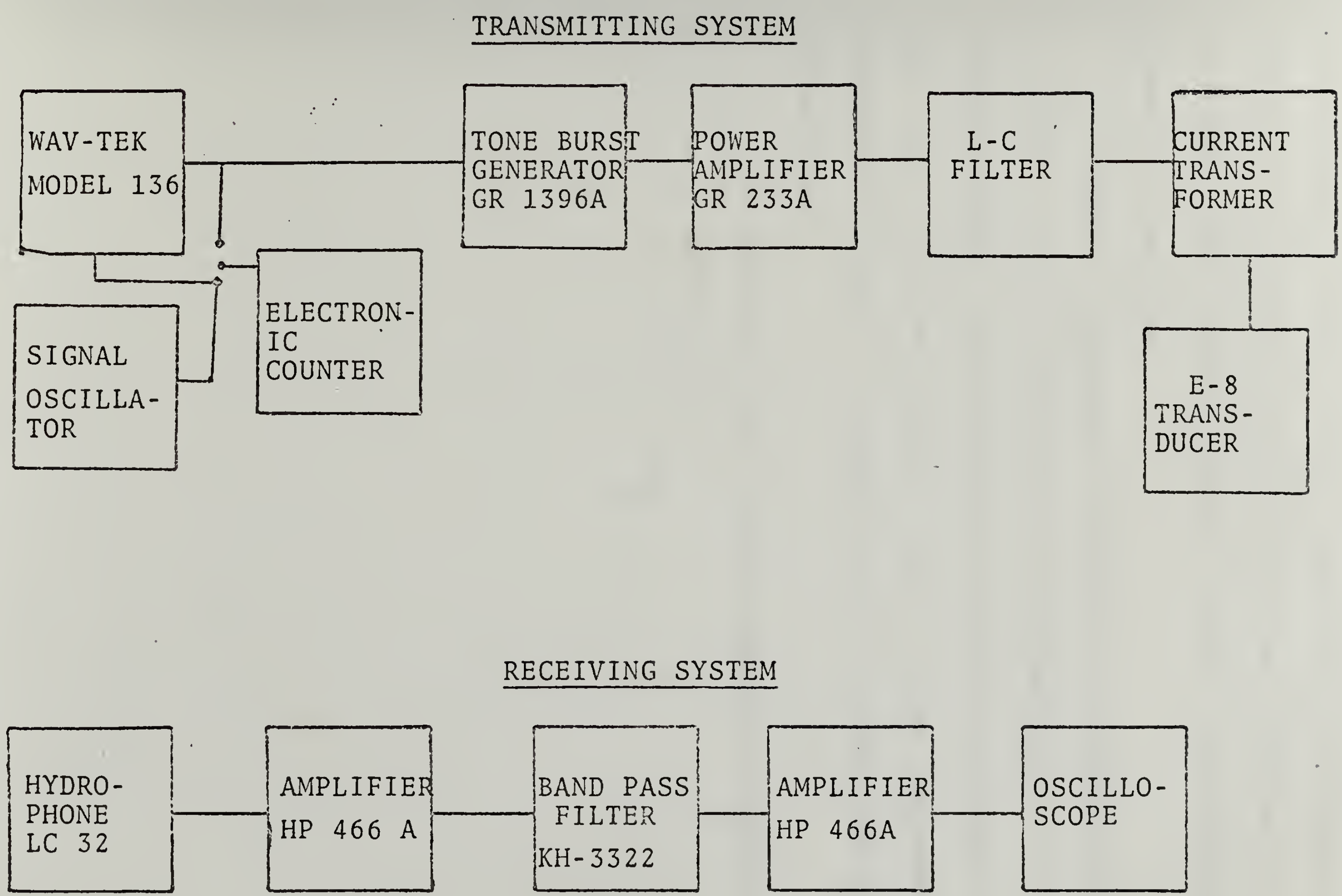
TRANSMITTING SYSTEM
WAV-TEK MODEL 136
TONE BURST GENERATOR GR 1396A
POWER AMPLIFIER GR 233A
L-C FILTER
CURRENT TRANS-FORMER
SIGNAL OSCILLA-TOR
ELECTRON-IC COUNTER
E-8 TRANS-DUCER
RECEIVING SYSTEM
HYDRO-PHONE LC 32
AMPLIFIER HP 466 A
BAND PASS FILTER KH-3322
AMPLIFIER HP 466A
OSCILLO-SCOPE

FIG 1

1. <u>Amplitude Modulation</u>

The output of the signal oscillator (of frequency f_1) is connected to the "VCA IN" connector of the Wavetek. The frequency (f_2) of the Wavetek function generator was set to 1.438 MHZ. The Wavetek was set for the amplitude modulation scheme of operation.

The E-8 transducer transmits the frequencies f_2, F_2-f_1, f_2+f_1. Due to the non-linearity of the transmitting medium, the hydrophone receives the frequencies $[f_2 - (f_2 - f_1)]$ and $(f_2+f_1 - f_2)$ i.e. two components of frequencies $f_1$only. A signal at $2f_1$ is also present but was filtered out.

The observed data for the amplitude modulation scheme is as shown in Table No. 1.

TABLE NO. 1

Attenuator (Wavetek) Setting - 20dB

Gain in Receiving Circuit = 60dB

Distance between E-8 and LC32 = 1 meter

Irms = 0.3 amp

S.No	Modulating Freq. in KHZ f_1	Freq. recd. by LC32 in KHZ	VL in dB
1.	25	25	-9.9
2.	30	30	-9.0
3.	40	40	-8.6
4.	50	50	-8.2
5.	55	55	-7.1
6.	60	60	-5.1
7.	70	70	-5.8
8.	80	80	-7.1
9.	90	90	-8.2

The Band Pass filter could not handle frequencies beyond 90 KHZ and frequencies below 30 KHZ were being distorted by the system.

The VL of the signal from the hydrophone with this method of modulation, corresponding to Irms = .3 amp is plotted against the frequency in Fig. 2.

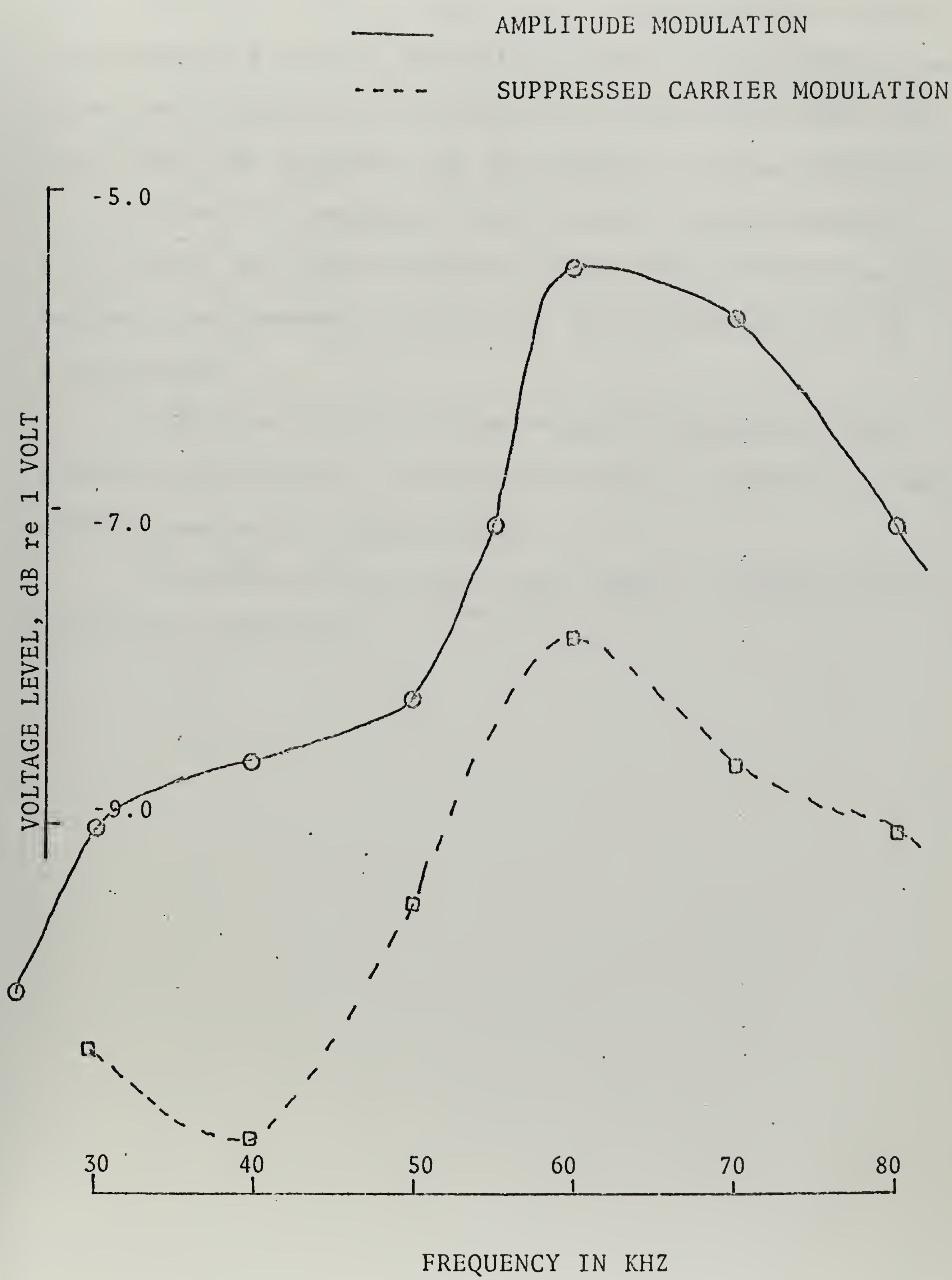
AMPLITUDE MODULATION
SUPPRESSED CARRIER MODULATION
VOLTAGE LEVEL, dB re 1 VOLT
-5.0
-7.0
-9.0
30
40
50
60
70
80
FREQUENCY IN KHZ

FIG 2

2. <u>Suppressed Carrier Modulation</u>

The circuitry was the same as in the case of amplitude modulation scheme except that the Wavetek was set for the suppressed carrier modulation scheme of operation. Let f_1 be the frequency of the output of oscillator model 120 and f_2 was the frequency of the Wavetek function generator.

The E-8 transducer will transmit two frequencies f_1+f_2 and f_1-f_2. Due to the non-linearity of the transmitting medium, the frequency received by the hydrophone will be $2f_1$, and $2f_2$.

The observed VL of the received signal with this scheme of modulation, is plotted in Fig. 2 against the various frequencies of transmission.

The observed data for this scheme of modulation is as shown in Table No. 2.

TABLE NO. 2

Attenuator (Wavetek) Setting = 20 dB

Gain in Receiving Circuit = 60 dB

Distance between LC32 and E-8 = 1 meter

RMS input current = 0.30 A

S.No	Modulating Freq. in KHZ	Freq. recd. by LC32 in KHZ	VL dB
1.	25	50	-9.5
2.	30	60	-7.8
3.	35	70	-8.6
4.	40	80	-9.0
5.	45	90	-10.4
6.	20	40	-11.0
7.	15	30	-10.4
8.	10	20	

It seems the system was good for frequencies between 30 KHZ and 90 KHZ. The maximum VL was observed at 60 KHZ. The amplitude modulation was better than the suppressed carrier modulation as far as the VL was concerned.

C. TABLE OF BEAM WIDTH (6dB) VS MODULATING FREQUENCY

The equipment was set up as in Fig. 1 with the following settings.

Attenuator setting (Wavetek) = 20dB

Wavetek generator frequency = 1438 KHZ

Gain in the receiver circuit = 60 dB

Distance between E-8 and LC32 = 1 meter

The amplitude modulation was used for this experiment (this being the better mode of modulation).

The modulating frequency was changed and corresponding beam width was recorded. The hydrophone was mounted on a moveable track and beam width was measured by making a lateral scan of the field.

The peak to peak voltage output of LC32 was taken from oscilloscope and 6dB down was taken to be the half of the voltage observed when LC32 was on axis (facing directly).

The data is in Table No. 3.

TABLE NO. 3

The rms current input to the E-8 transducer was kept constant at .30 Amps for all the following readings.

S.No.	Freq. in KHZ	6dB Beam-width in cms.	6dB Beam-width in degrees
1.	30	15.3	8.7^o
2.	40	12.8	7.3^o
3.	50	10.9	6.2^o
4.	60	10.1	5.8^o
5.	70	10.6	6.1^o
6.	80	10.0	5.7^o
7.	90	10.4	6.0^o

It seems that 60 KHZ modulating frequency is most suited from the point of view of signal strength as well as that of the beam width.

D. VARIATION OF SPL WITH RANGE AND THE BEAM PATTERN FOR THE OPTIMUM CONDITIONS

Two additional experiments were conducted to measure

(i) the difference frequency SPL vs. range, and

(ii) the beam pattern

under the optimum conditions of the system. In these experiments the following parameters were used.

The frequency of modulation used was 60 KHZ. The Wavetek was set for the amplitude modulation scheme. The input

current to the E-8 transducer was selected to be 0.3 amps. to avoid any distortion of the signal. The primary frequency, i.e. the frequency of the Wavetek function generator was set at 1438.0 KHZ.

In experiment No. 1, the band pass filter setting in the receiver circuit was set to the range of 30 to 90 KHZ with a total receiving gain of 60 dB. The hydrophone was moved from r = 50 cms. to 4 = 235 cms. The SPL at various distances is shown in Fig. 3. It was observed that the maximum SPL was 46.2 dB reference one microbar obtained between 90 and 120 cm. The data taken is shown in Table No. 4.

In experiment No. 2, the beam pattern of the parametric source was measured at a range of 170 cms. The reason for selecting this particular value was to obtain some sort of comparison with the experiment No. 1 of section III at the same range. The receiving gain was 80 dB and the filter pass band was set to 40-70 KHZ. The beam pattern is shown in Fig. 4 and the data taken is shown in Table No. 5.

It was found that the parametric source had no side lobes and the maximum SPL for this range was observed to be 42.85 dB reference one microbar when both the transducer and the hydrophone were on the acoustic axis.

TABLE NO. 4

Range in cm.	SPL in dB
50	42.7
60	44.0
70	45.15
80	45.85
90	46.18
100	46.18
110	46.18
120	46.18
130	45.85
140	45.51
150	45.15
160	44.78
170	44.78
180	44.40
190	44.00
200	43.58
210	43.58
220	43.12
230	43.12
235	43.12

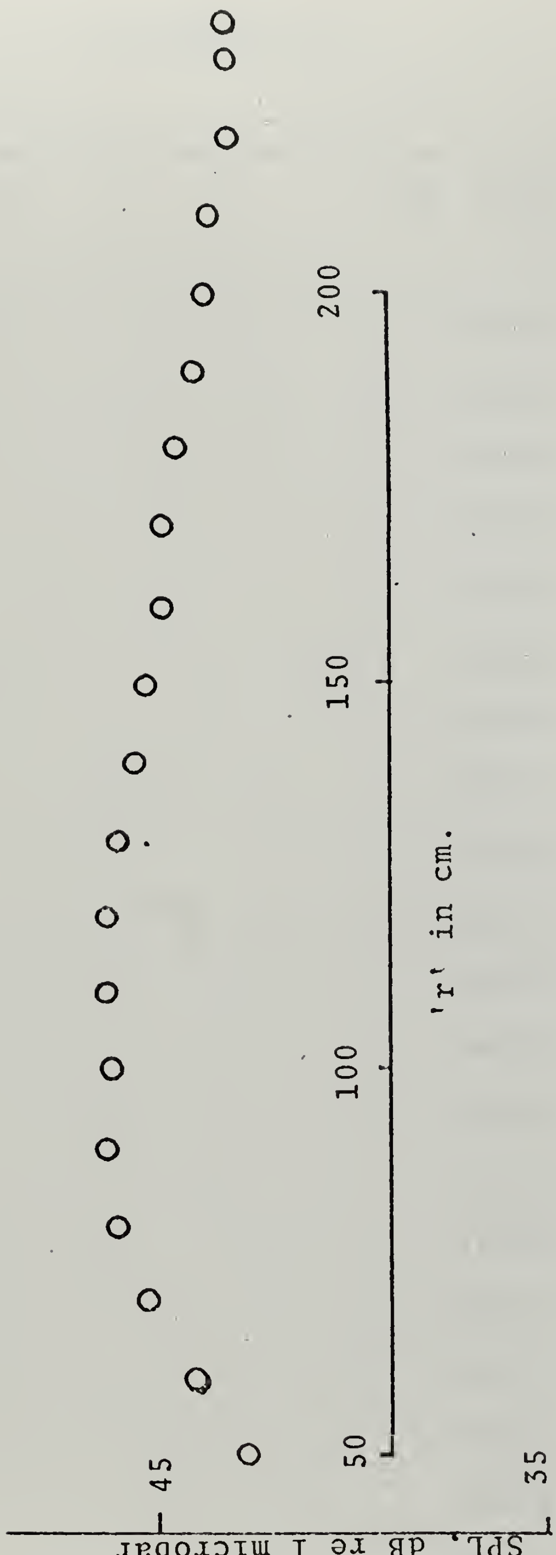

FIG 3

TABLE NO. 5

"a" in cm.	SPL in dB
0	42.85
1	42.85
2	42.46
3	41.85
4	41.19
5	40.22
6	39.42
7	38.53
8	37.89
9	36.44
10	35.61
11	34.69
12	33.67
13	32.51
14	31.90
15	31.17
16	30.42
17	29.59
18	28.68
19	28.18
20	27.65

REMARKS: These readings are to the left of the acoustic axis.

TABLE NO. 5 (contd.)

"a" in cm.	SPL in dB
0	42.85
1	42.85
2	42.46
3	42.01
4	41.40
5	40.72
6	39.69
7	38.84
8	37.89
9	36.83
10	35.83
11	34.90
12	34.20
13	33.39
14	32.51
15	31.90
16	31.17
17	30.42
18	29.59
19	29.15
20	28.18

REMARKS: These readings are to the right of the acoustic axis.

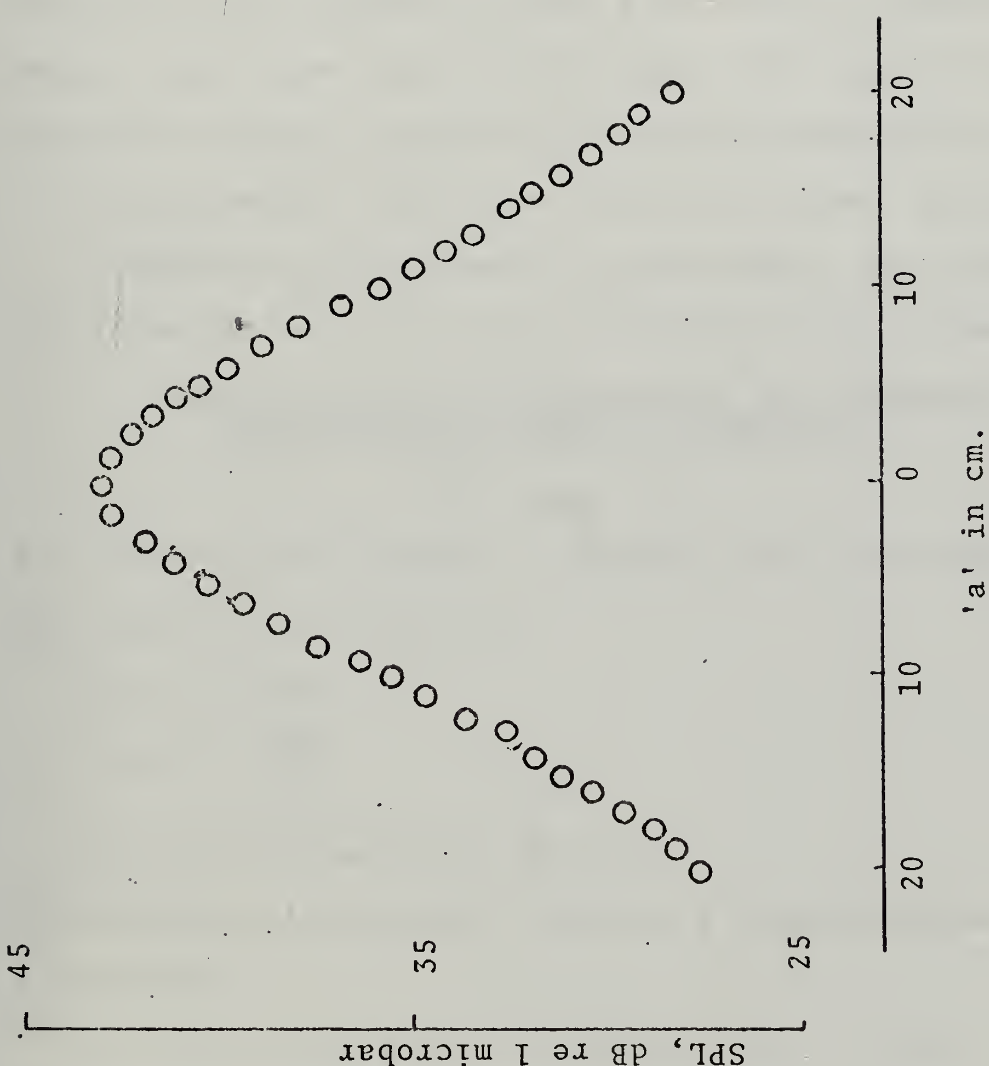

FIG 4

III. SURFACE REFLECTION OF THE PARAMETRIC BEAM

A series of six experiments was performed to examine the reflection of an acoustic parametric beam from a still water air surface, in the nearfield of the parametric array. The transducer was mounted in such a way that it could be tilted at any angle from the acoustic axis. The angle of inclination "θ" from the acoustic axis could be measured.

The geometric single ray pattern is shown in Fig. 5.

Considering the geometry of the setup, the hydrophone should be placed at the point "R" to get the maximum signal.

<u>CALCULATIONS FOR DETERMINING THE DISTANCE OF HYDROPHONE FROM THE TRANSDUCER</u>

(ref. Fig. 5)

S'A' is the water surface; transducer E8 is at point S and the receiver is at point R.

SS' = 47 cms.

$$\tan 30 = \frac{AA'}{AS}$$

$$AS = (AA')/(\tan 30) = \sqrt{3} \times 47$$

Theoretically LC32 should register a maximum signal at r = 162 cms.

As seen in the plot of experiment no. 3 (Fig. 6), the maximum signal was realized at r = 170 cm.

This discrepancy in theory and experiment is attributed to the errors incorporated due to the measurements of the depth and the angle of inclination of the transducer.

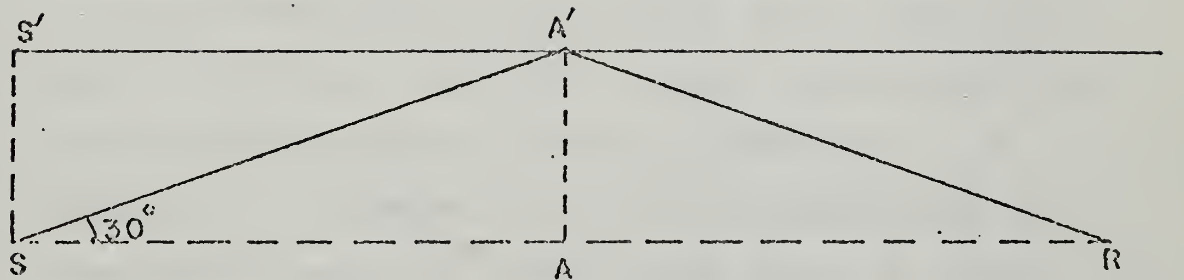

FIG 5

A. ANGLE OF INCLINATION OF 30^{o} AND fm = 60 KHZ

In the following two experiments the SPL was measured as a function of horizontal range "r" along the axis, and as a function of lateral distance "a" from the axis at the range of 170 cm.

The angle of inclination was set at 30^{o} and the frequency of modulation was 60 KHZ for the following two experiments.

1. In experiment no. 1. the SPL at different ranges was observed and the results are shown in Fig. 6 and Table 6.

   The maximum SPL was observed to be 32.2 dB reference one microbar. The SPL of 42.85 was observed for direct transmission as in the experiment no. 2 of section II. It means that in this configuration of experiment there is a loss of about 10 dB on reflection. The parametric wave transmission does not agree with the Lloyd mirror reflection theory of the conventional sound wave transmission as in the case of the latter there is hardly any loss.

2. In experiment no. 2. the purpose was to obtain the beam pattern of the reflected parametric wave. The results SPL vs. "a" are shown in Fig. 7 and Table 7 for a horizontal range of 170 cm.

   The reflected parametric beam has definite side lobes. The side lobes are 1.5 dB down compared to the main lobe.

TABLE NO. 6

"r" in cm.	SPL in DB	"r" in cm.	SPL in dB
100	-	174	32.04
110	13.10	178	31.53
120	17.60	180	30.80
130	22.20	182	30.61
140	26.80	184	30.42
141	27.10	186	30.42
142	27.10	188	30.61
144	27.65	189	30.61
146	27.92	190	30.61
148	27.92	192	30.61
150	27.66	194	30.80
152	27.40	196	30.80
154	26.80	198	30.61
156	26.80	200	30.42
158	27.10	202	30.42
160	27.92	204	30.22
162	29.15	208	29.81
164	30.22	210	29.59
166	31.17	220	28.68
168	31.87	230	26.50
170	32.20	235	25.15
172	32.04		

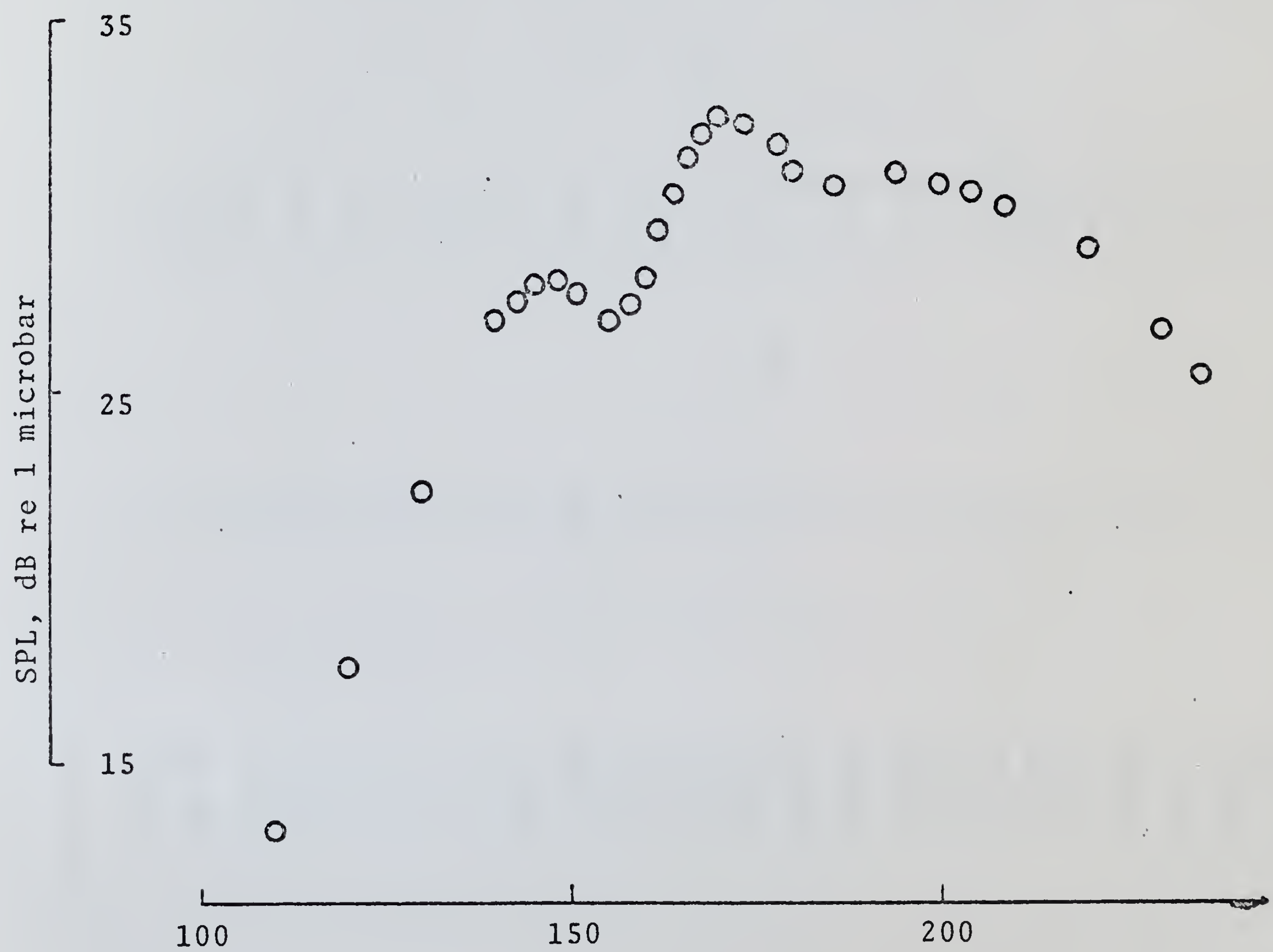

FIG 6

TABLE NO. 7

"a" in cm. (to right of acoustic axis)	SPL in dB	"a" in cm. (to left of acoustic axis)	SPL in dB
0	32.20	0	32.20
1	32.04	1	32.04
2	31.70	2	31.70
3	31.17	3	31.00
4	30.61	4	30.42
5	30.01	5	29.81
6	29.59	6	29.37
7	29.37	7	28.91
8	29.59	8	29.15
9	30.01	9	29.37
10	30.22	10	29.59
11	30.42	11	29.81
12	30.61	12	30.01
13	30.61	13	30.22
14	30.42	14	30.22
15	30.22	15	30.01
16	30.01	16	29.81
17	29.81	17	29.59
18	29.37	18	29.37
19	29.15	19	28.91
20	28.68	20	28.43
21	28.13	21	27.65
22	27.65	22	27.10
23	26.80	23	26.50
24	25.85	24	25.51

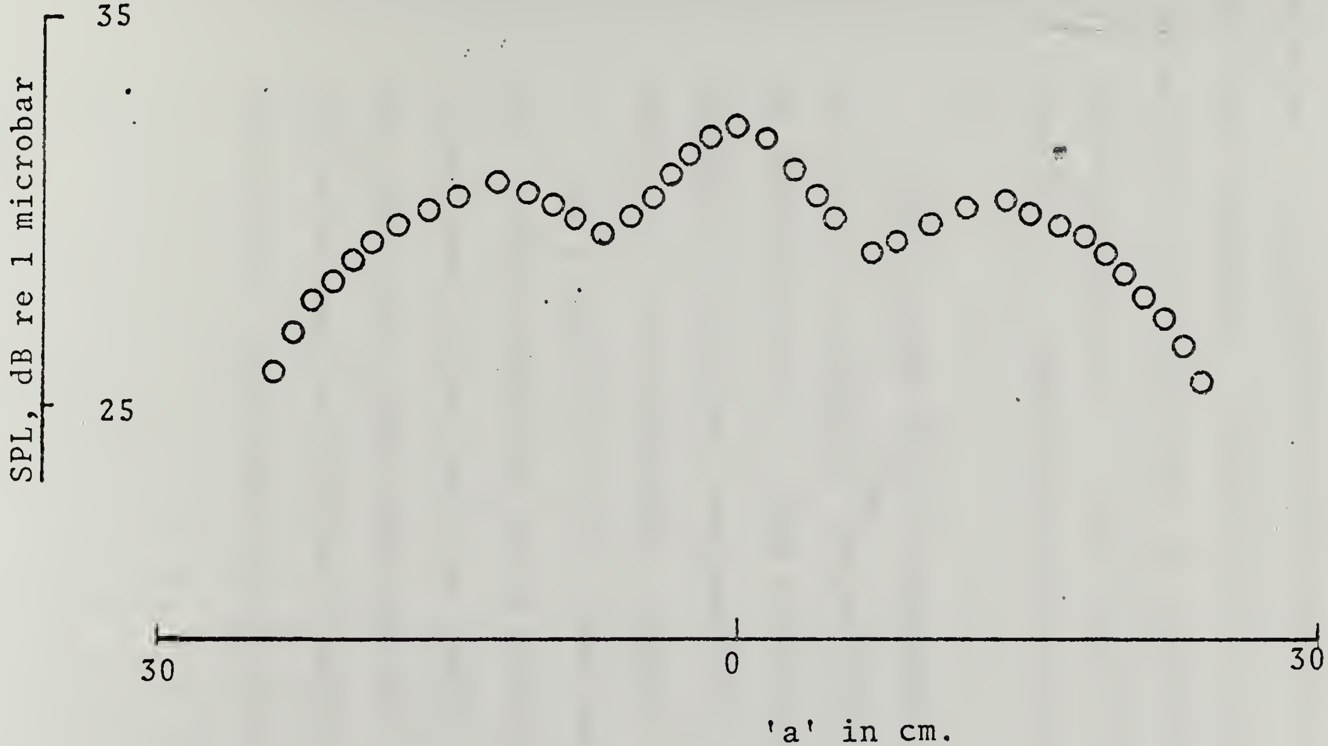

FIG 7

B. ANGLE OF INCLINATION OF 30^o AND fm = 20 KHZ

In the following two experiments the relative pressure level was measured as a function of horizontal range "r" along the axis and as a function of lateral distance "a" from the axis at a range of 170 cm.

The angle of inclination was set at 30^o and the frequency of modulation was 20 KHZ for these two experiments. For convenience, the hydrophone calibration at 50 KHZ is used at this lower frequency. Some error is likely in this assumption but it is not important in the present context.

1. In experiment no. 1, the SPL at different ranges was observed and the results are shown in Fig. 8 and Table 8.

   The maximum relative pressure level was found to be 28.91 dB reference one microbar.

2. In experiment no. 2, the beam pattern of the reflected parametric beam was obtained as shown in Fig. 9 and Table 9, for a horizontal range of 170 cm.

   The presence of side lobes was again observed as was in experiment No. A2 of section III. The side lobes were about 5 dB down compared to the main lobe. Also the side lobes found in this experiment were at a greater angular distance compared tc the ones in the case of experiment A2 of section III.

TABLE NO. 8

"r" in cm.	SPL in dB	"r" in cm.	SPL in dB
90	15.67	168	28.63
100	19.13	170	28.91
110	21.63	172	28.68
120	25.51	174	28.43
122	25.51	176	27.92
124	26.20	178	27.40
126	26.50	180	27.10
128	26.80	190	24.40
130	26.50	192	24.00
132	26.50	194	23.60
134	26.20	196	23.60
136	25.51	198	23.60
138	25.15	200	23.60
140	25.15	202	23.60
142	24.40	204	23.12
144	24.40	206	23.12
146	24.80	208	23.12
148	24.80	210	23.12
150	25.15	212	23.12
160	26.80	214	23.12
162	27.40	220	23.12
164	27.92	230	22.65
166	28.43	235	22.20

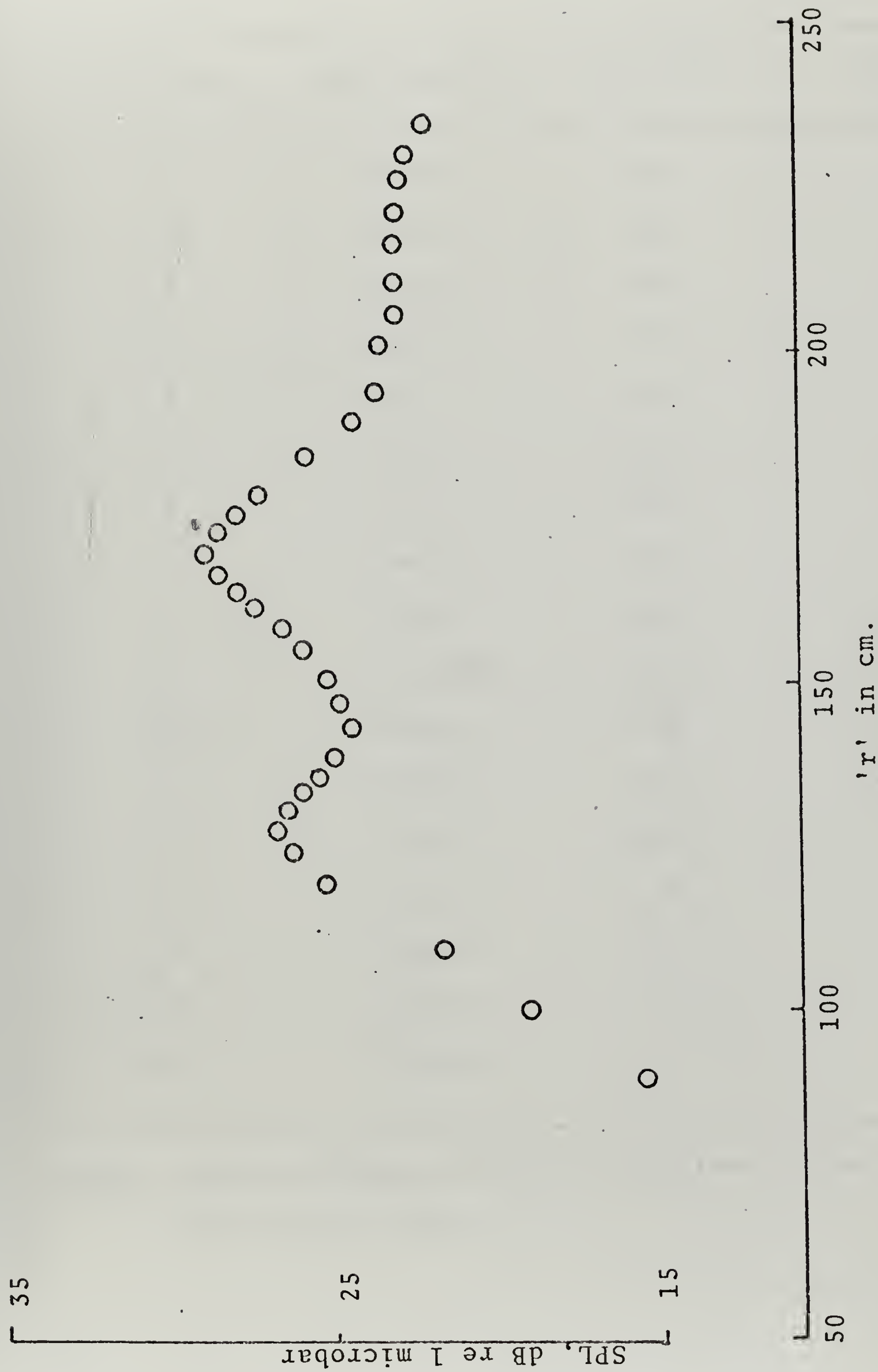

FIG 8

TABLE NO. 9

"a" in cm.	SPL in dB	"a" in cm.	SPL in dB
0	28.91	17	23.60
1	28.68	18	23.60
2	28.43	19	23.60
3	27.66	20	23.60
4	27.10	21	23.60
5	26.20	22	23.60
6	25.15	23	24.00
7	24.40	24	24.00
8	24.00	25	24.00
9	23.12	27	24.00
10	23.12	29	23.60
11	22.65	31	23.12
12	22.65	33	23.12
13	22.65	35	22.65
14	23.12	37	22.20
15	23.12	40	21.63
16	23.60		

NOTE: These readings are for the receiver to the left of the acoustic axis.

TABLE NO. 9 (contd.)

"a" in cm.	SPL in dB	"a" in cm.	SPL in dB
0	28.99	21	23.60
1	28.99	22	23.60
2	28.68	23	23.60
3	28.18	24	24.00
4	27.66	25	24.00
5	26.80	26	24.00
6	25.85	27	24.00
7	25.15	28	24.00
8	24.40	29	23.60
9	24.00	30	23.60
10	23.60	31	23.60
11	23.12	32	23.12
12	23.12	33	23.12
13	22.65	34	22.65
14	22.65	36	22.20
15	22.65	37	22.20
16	22.65	38	21.63
17	22.65	41	20.47
18	23.12	43	19.83
19	23.60	45	19.13
20	23.60		

NOTE: These readings are for the receiver to the right of the acoustic axis.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
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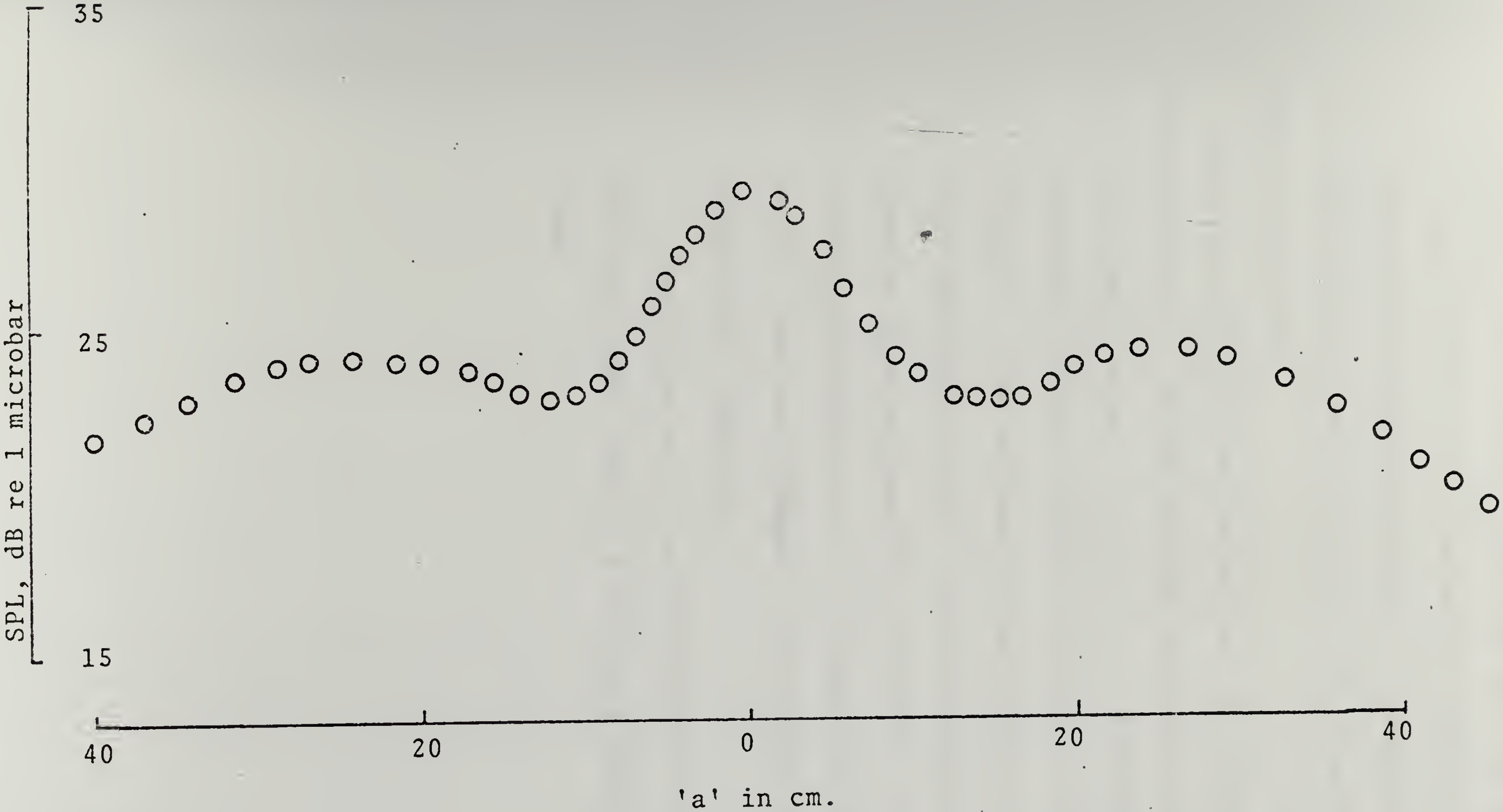

FIG 9

C. ANGLE OF INCLINATION OF 25^{o} AND fm = 60 KHZ

In the following two experiments, the SPL was measured as a function of horizontal range "r" along the axis, and as a function of lateral distance "a", from the axis at a range of 210 cm.

The angle of inclination was set at 25^{o} and the frequency of modulation was 60 KHZ for the following two experiments.

1. In experiment no. 1, the SPL at different ranges was observed and the results are shown in Fig. 10 and Table 10. The maximum SPL was observed to be 32.53 dB reference one microbar which was approximately the same as in experiment No. A1 of this section.
2. In the experiment no. 2, the beam pattern of the parametric beam was observed; the results are shown in Fig. 11 and Table 11.

   The presence of the side lobes were again detected. The side lobes were 1.5 dB down compared to the main lobe.

TABLE NO. 10

"r" in cm.	SPL in dB
140	19.13
150	21.63
160	25.15
170	29.15
172	29.59
174	30.01
176	30.22
178	30.42
180	30.61
182	30.42
184	30.42
186	30.01
188	29.59
190	29.15
192	28.91
200	30.42
202	31.00
204	31.70
206	32.20
208	32.51
210	32.53
212	32.53
214	32.53
216	32.51
218	32.20
220	31.90
230	31.17
235	31.35

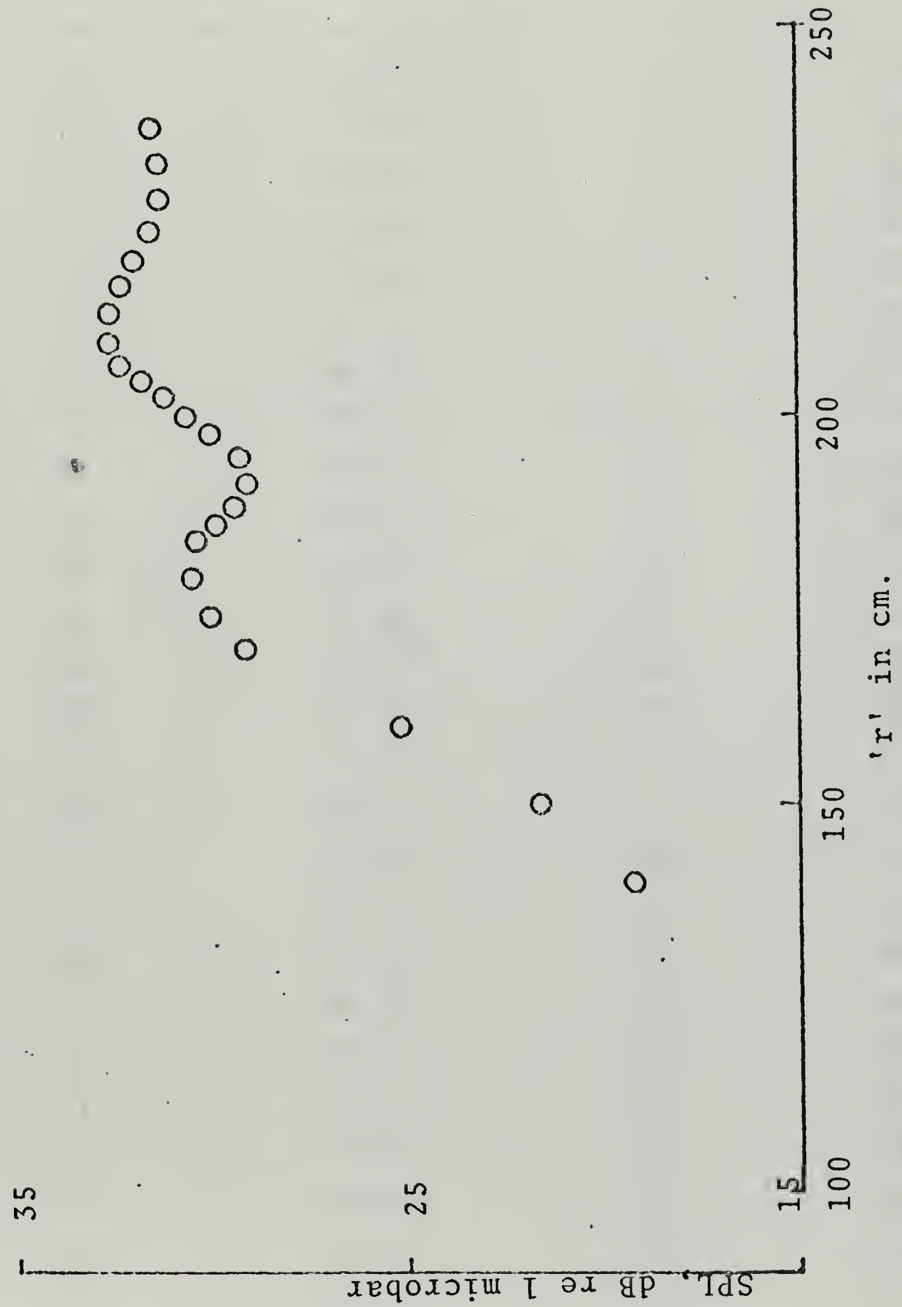

FIG 10

TABLE NO. 11

"a" in cm. (to left of acoustic axis)	SPL in dB	"a" in cm. (to right of acoustic axis)	SPL in dB
0	32.53	0	32.53
1	32.53	1	32.53
2	32.51	2	32.36
3	32.36	3	31.90
4	31.90	4	31.35
5	31.35	5	31.00
6	30.80	6	30.80
7	30.42	7	30.61
8	30.22	8	30.61
9	30.22	9	30.80
10	30.22	10	31.00
11	30.42	11	31.17
12	30.80	12	31.35
13	31.00	13	31.35
14	31.17	14	31.35
15	31.17	15	31.35
16	31.17	16	31.17
17	31.17	17	31.00
18	31.00	18	30.80
19	30.80	19	30.42
20	30.61	20	30.01
21	30.22	21	29.51
22	29.81	22	29.15
23	28.68	23	28.68
24	28.68	24	28.18
25	28.18	25	27.66

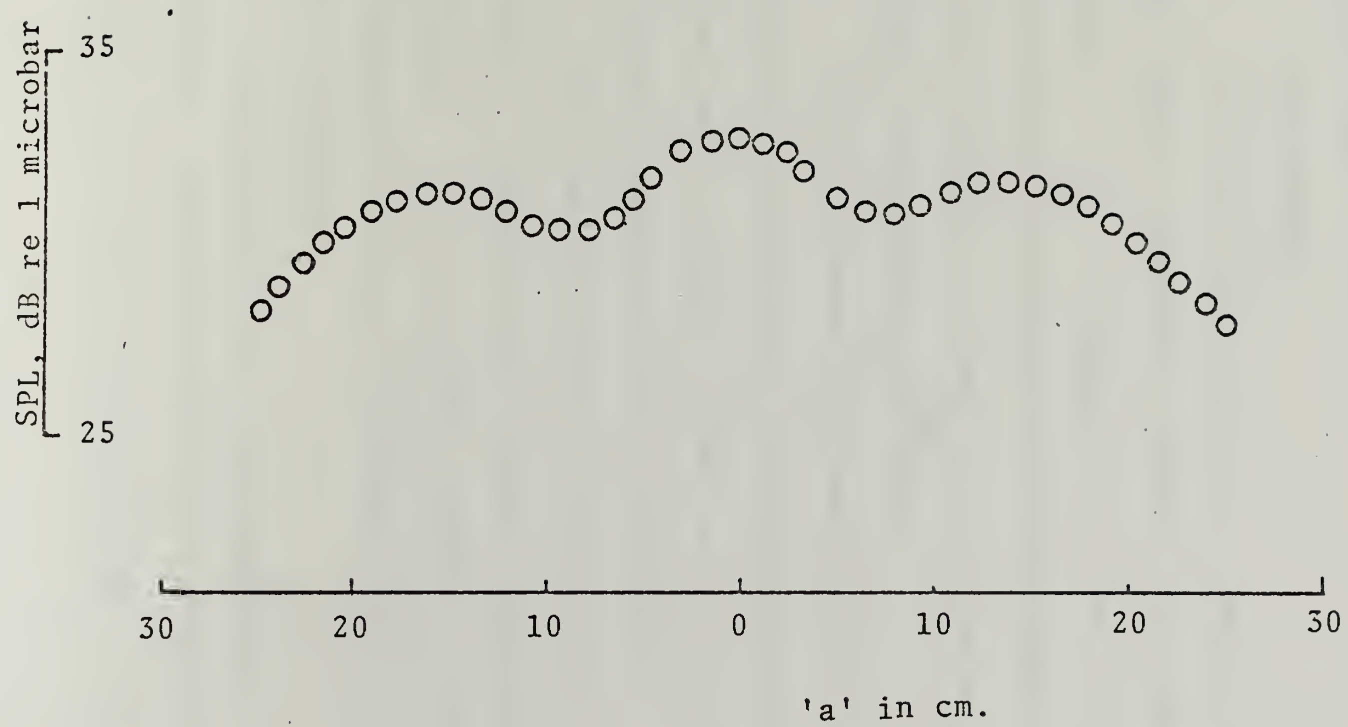

FIG 11

IV. PARAMETRIC WAVE TRANSMISSION AT SEA

The last phase of the thesis was to observe the performance of the parametric source in sea water and compare it with the performance in the laboratory.

A. DESCRIPTION OF APPARATUS AND CIRCUITRY. COEFFICIENT OF VARIATION

1. The Mounting

The apparatus designed as a mount was a square of height 180 cm. and length 160 cms. from the face of the transducer to the receiving hydrophone as shown in Fig. 12. Three sides of the mount were of two inch diameter steel pipe and the fourth was a 0.04 inch steel wire, shoch mounted to the frame for vibration isolation.

The E-8 (parametric sound source) and F-33 (the conventional sound source) were mounted one on top of the other and were slightly tilted so that the acoustic axis of each passed through the LC32 hydrophone.

The completed design combined two necessary characteristics -- rigidity and minimum self-generated hydrodynamic turbulance. The end of the apparatus holding the transducer was necessarily massive to ensure rigidity about the propagating transducer.

The wire served as the mounting for the receiver hydrophone. Since the receiving hydrophone was quite light in weight, the wire was rigid enough. Also, the small size

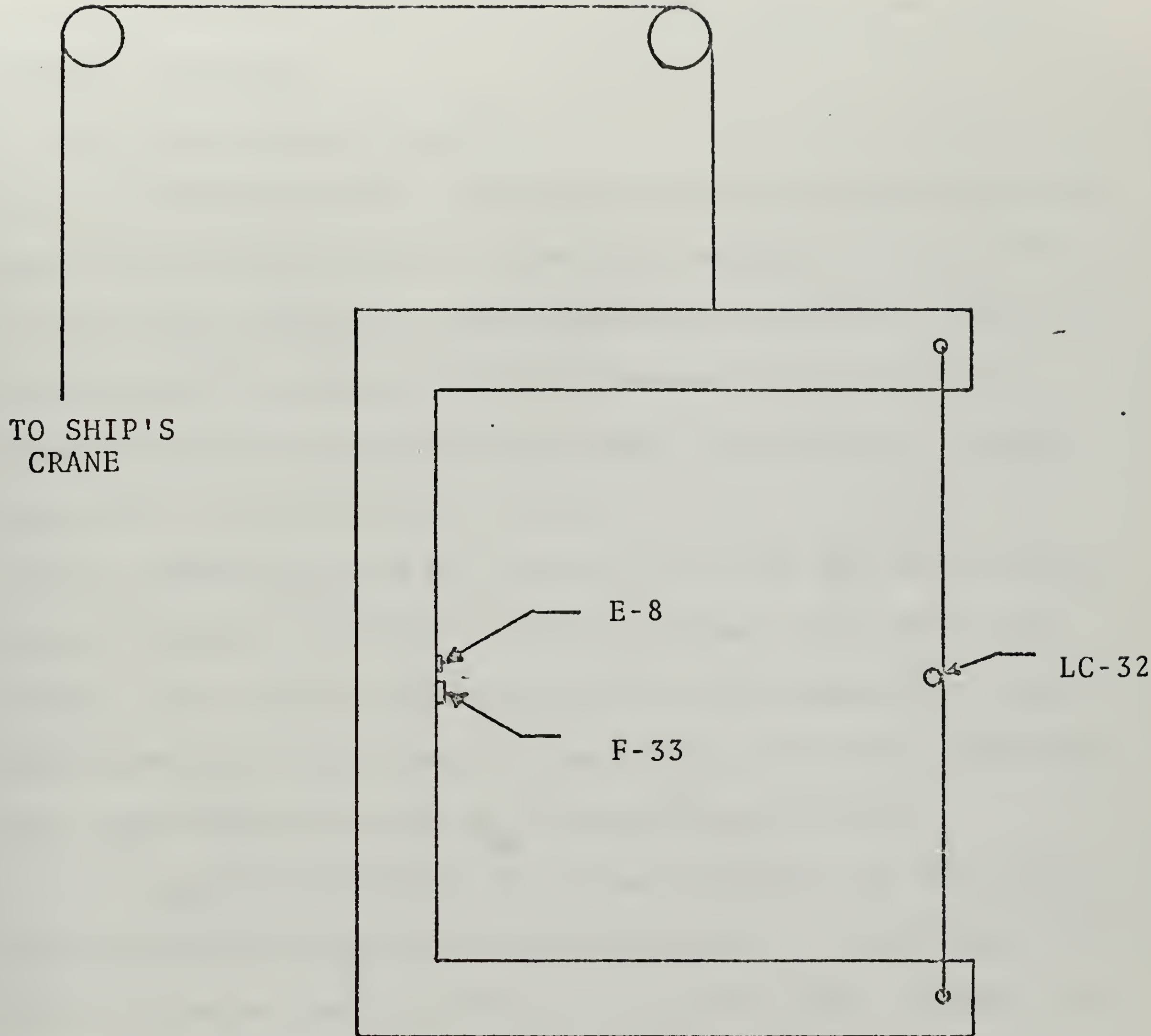

FIG 12

of the wire avoided the presence of any significant hydrodynamic turbulance.

2. <u>Transmitter Circuit</u>

The transmitter circuit was not modified and was the same as described earlier. Two drum switches (2 positions, 4 ways) were inserted in the transmitter circuit. This was incorporated to switch from E-8 (parametric sound transmission) to F-33 (conventional sound transmission) instantaneously. It may be noted that F-33 did not require (i) primary frequencies of the order of 1.4 MHZ and hence there was no need for the Wavetek in its circuit (ii) High Pass filter. The 60 KHZ signal was fed to the tone burst generator directly in the case of the F-33. All these operations were simultaneously done by the two drum switches.

A cable of length 76 ft. was attached to the E-8 to have sufficient length for shipboard use. It was noted that, with the longer cable attached to the E-8, more current was drawn from the power amplifier. The greater current, however, did not correspond to a stronger signal at the difference frequency.

3. <u>Receiver Circuit</u>

The received signal in the laboratory was steady as there was no wind and no inhomogenities in the fresh water of the tank. A varying signal was expected at sea due to wind and inhomogenities in sea water. As such it was wanted to measure the coefficient of variation besides measuring SPL at various frequencies of transmission.

The receiver circuit was modified as shown in Fig. 13. Power amplifier 467A was inserted to the original circuit described in Fig. 1. This was done to obtain a more flexible gain control for measuring the weak signal. Output of the amplifier 466A was fed to an envelope detector, which is shown in Fig. 14. This detector was designed and fabricated in the laboratory by Professor Eller. The output of the envelope detector was taken to three parallel circuits.

(i) Channel 1 of Clevite Brush Mark 220 strip chart recorder.

(ii) Precision Instrument PI-6200 tape recorder.

(iii) R-C network filter which is shown in Fig. 15.

The output of the R-C network was recorded on channel 2 of the strip chart recorder.

<u>Coefficient of Variation</u>: Reference Fig. 16.

Let $A(t)$ be the amplitude at any instant of time.

$\bar{A}$ be the average value of $A(t)$.

CV be the coefficient of variation.

$$CV = \left[\frac{\langle A^2 \rangle - (\bar{A})^2}{(\bar{A})^2} \right]^{\frac{1}{2}}$$

$$= \left[\frac{(A - \bar{A})^2}{(\bar{A})^2} \right]^{\frac{1}{2}}$$

$$CV = \frac{(A - \overline{A})_{RMS}}{\overline{A}}$$

Percentage CV = CV x 100.

The signal was passed to an envelope detector (demodulator) which gave the envelope of the difference-frequency signal; the high-frequency primaries were by-passed.

The output of the envelope detector was recorded on tape as well as on channel 1 of the strip chart recorder. This output was next passed through an R-C filter which blocked the D.C. component of A (t) and passed its low-frequency fluctuations. The output of this filter gave $(A - \overline{A})$, which was recorded on channel 2 of the strip chart recorder. Both channels of the strip chart recorder were operated simultaneously.

MODIFIED RECEIVER CIRCUIT

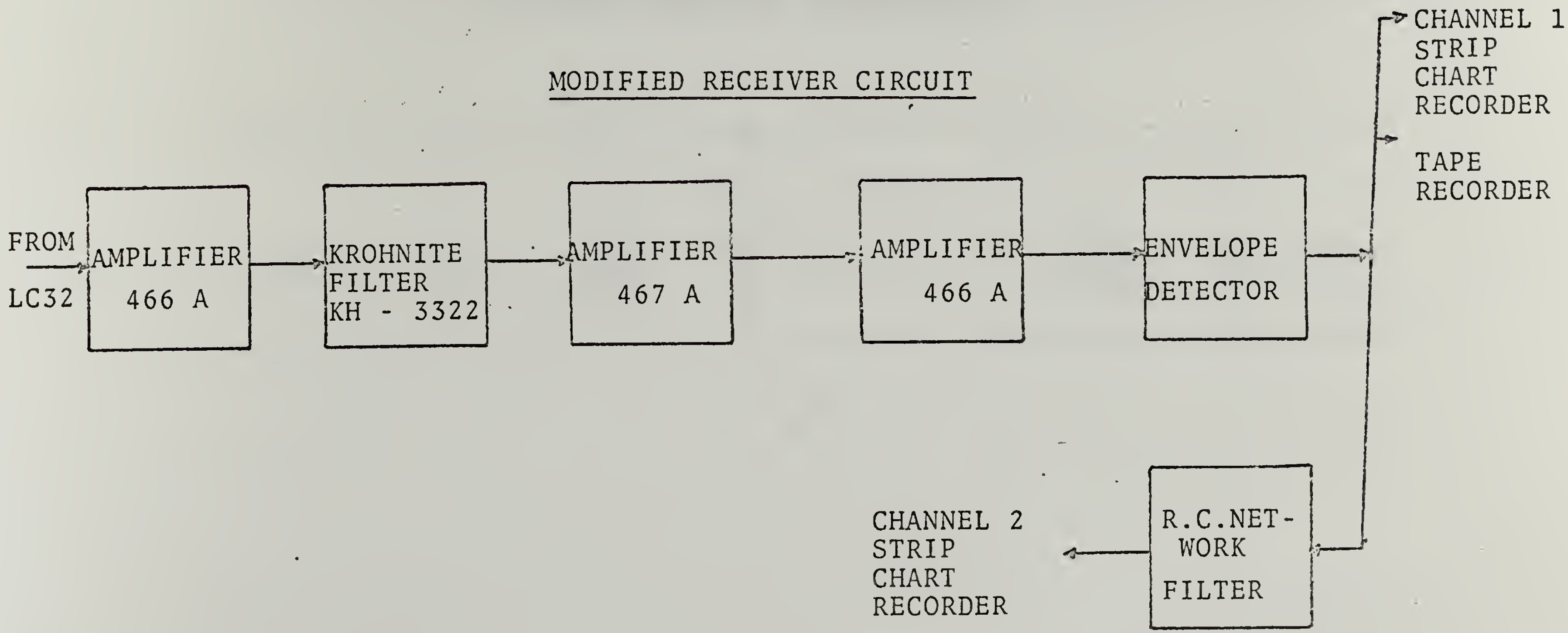

FIG 13

ENVELOPE DETECTOR (DEMODULATOR)

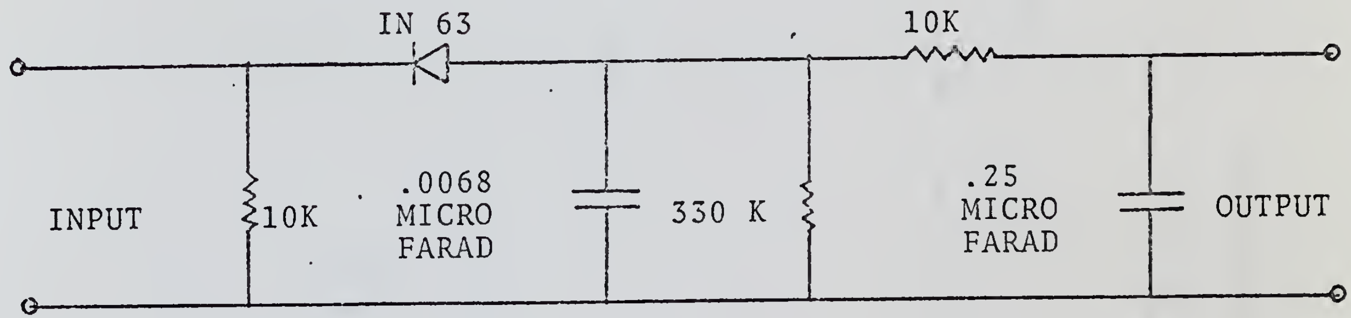

FIG 14

R.C. FILTER

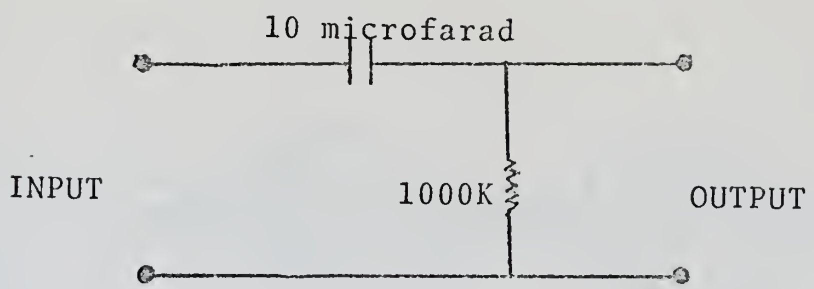

FIG 15

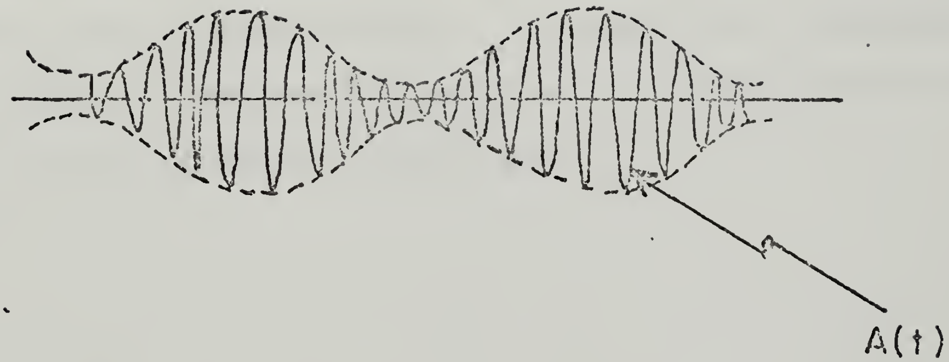

FIG 16

B. FREQUENCY RESPONSE OF THE NEW SYSTEM IN THE LABORATORY

The set up designed for the ship-board use was placed in the fresh water tank of the laboratory. The voltage level of the received signal at the difference frequency was measured with varying modulating frequencies. The amplitude modulation mode was used.

The following parameters were held constant:

G = 60 dB, RMS Driving Current = 0.5 amps, fr = 1355 KHZ.

The plot of received voltage level Vs fm is illustrated in Fig. 17 and recorded in Table 12.

TABLE NO. 12

fm in KHZ	Receiver Bandwidth in KHZ	Voltage level 20 log $\frac{\text{Vrms}}{\text{1 volt}}$
20	10-30	-17.8
30	10-50	-17.8
40	20-70	-17.0
50	30-90	-15.0
60	30-90	-13.5
70	30-99	-14.2
80	30-99	-17.0
90	30-99	-19.5

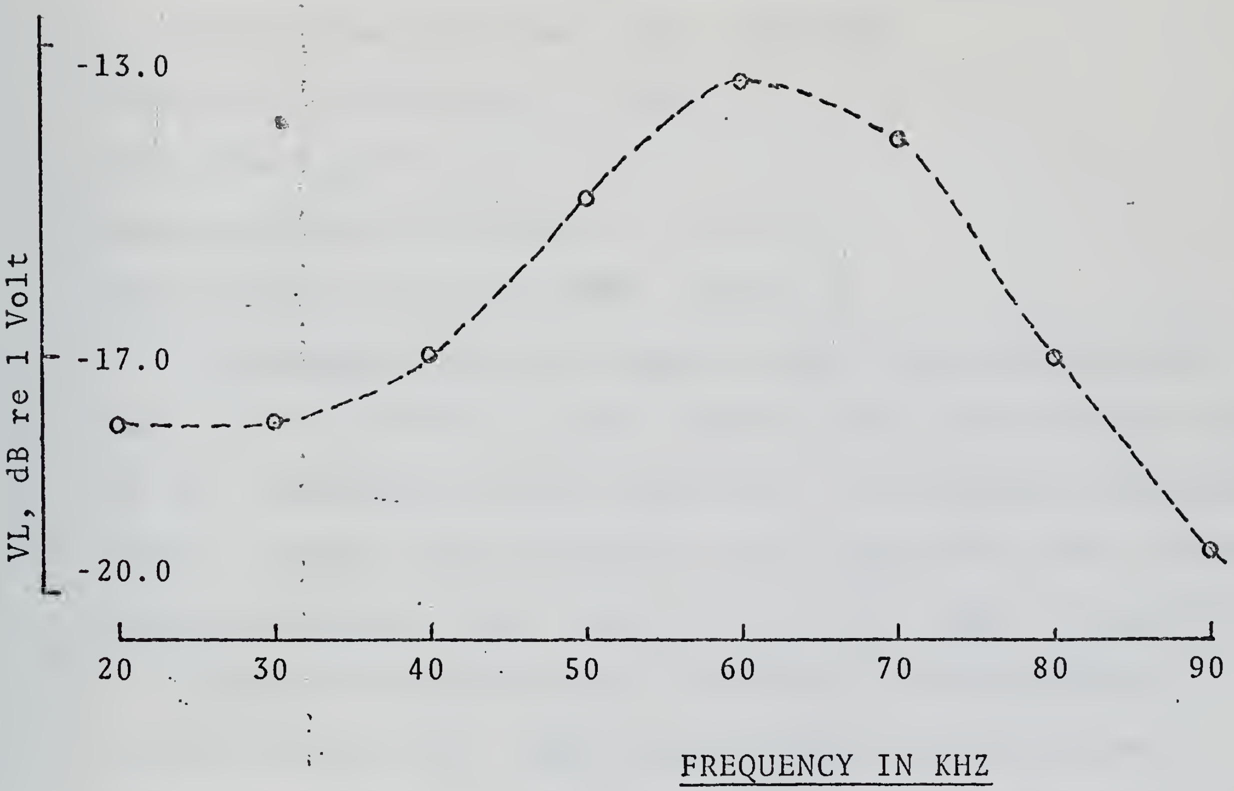
-13.0
-17.0
-20.0
VL, dB re 1 Volt
20
30
40
50
60
70
80
90
FREQUENCY IN KHZ

FIG 17

C. FREQUENCY RESPONSE OF THE NEW SYSTEM AT SEA

The equipment was taken on board the R/V Acania and it was anchored in 60 ft. of water in Monterey Bay.

Difference frequency transmission readings were taken at depths of 40 ft., 20 ft., and 10 ft.

The received voltage was measured with varying modulating frequency from 20 to 90 KHZ and the results are plotted in Fig. 18 and Table 13.

The following parameters were held constant:

G = 60 dB, Irms = 0.5 amp., fr = 1352 KHZ.

Pulse repetition Rate = 2.5 ms.

Gate duration = 16 ms.

Temperature at sea surface - 16.23° C.

Temperature at 17 ft. depth - 16.43° C.

The maximum received signal voltage level obtained at sea was - 11.2 dB re 1 volt, when fm was 50 KHZ and the depth of the transducer in water was 40 ft. The maximum received signal voltage level observed in the laboratory under similar working parameter was - 13.5 dB re 1 volt, when fm was 60 KHZ.

There was no appreciable difference in the received signal voltage level when the experiment was conducted at sea or in the lab. It was, however, observed that the frequency response varied at various depths only to a small extent and was within 3 dB. The received signal at 50 KHZ at 40 ft. depth corresponds to an SPL of 41.4 dB re 1 microbar.

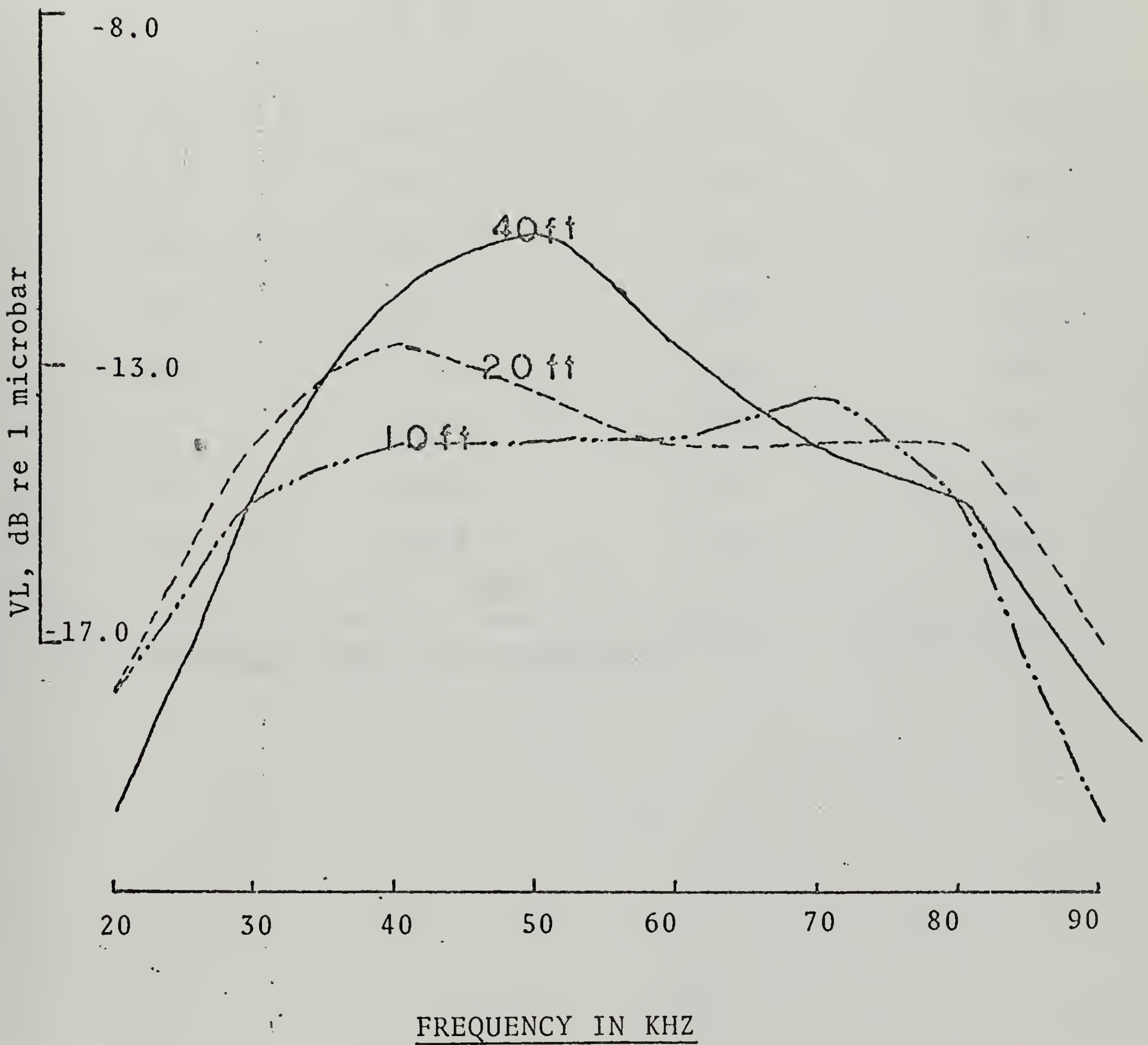
-8.0
-13.0
-17.0
VL, dB re 1 microbar
40ft
20ft
10ft
20
30
40
50
60
70
80
90
FREQUENCY IN KHZ

FIG 18

TABLE NO. 13

fm in KHZ	V.L. at 40 ft. in dB	V.L. at 20 ft. in dB	V.L. at 10 ft. in dB
20	-19.5	-17.8	-17.8
30	-15.0	-14.2	-15.0
40	-12.1	-12.8	-14.2
50	-11.2	-13.5	-14.2
60	-12.8	-14.2	-14.2
70	-14.2	-14.2	-13.5
80	-15.0	-14.2	-15.0
90	-17.8	-17.0	-19.5

V.L. = Voltage Level = 20 log Vrms.

D. CALCULATIONS OF COEFFICIENT OF VARIATION AND COMMENTS

The purpose of this experiment was to determine the coefficient of variation at various depths and frequencies for parametric and conventional sound propagation.

The equipment was rigged on board as mentioned earlier. Simultaneous strip chart and tape recordings were made of 60 seconds each for varying depths and frequencies. The tape recorder was operated in its fm mode.

The following parameters were held constant:

Tape speed - 3.75 IPS.

Filter setting on tape recorder - 100 CPS.

Strip chart speed - 5 mm/sec.

Channel 1 Scale - 200 mv/division.

Channel 2 Scale - 20 mv/division.

Receiver gain was varied to get appreciable signal.

The frequency of modulation was varied from 20 to 90 KHZ at the steps of 10 KHZ for F-33 and E-8. The three depths chosen for the experiment were 40 ft., 20 ft., and 10 ft.

Channel 1 of the strip chart recorded the A(t). By visual inspection one can then estimate the average $\bar{A}(t)$.

Channel 2 of the strip chart recorded $(A - \bar{A})$. The peak to peak value of $(A - \bar{A})$ was read from the chart and the r.m.s. value of the same was calculated by dividing by 2 2. Many readings of $(A - \bar{A})$ were taken at different parts of the strip chart and the mean was taken for getting mean r.m.s. value of $(A - \bar{A})$. The large signal variations due to passing fish, swells, tide etc. were neglected.

The coefficient of variation calculated at 40, 20, and 10 ft. is shown in Tables 14, 15, and 16 respectively.

It was noticed that the coefficient of variation was less than 3% for the depths of 20 ft. and 40 ft. CV was generally higher for E-8 than that for F33 at these depths.

At the transducer depth of 10 ft., CV depended on the ship's orientation and surface wave direction. CV was much greater at this depth than that of 40 and 20 ft. The largest value of CV at 10 ft. was observed to be 30%. Also CV for F33 was found to be greater than that for E-8 contrary to the observations at greater depths of 20 and 40 ft.

TABLE NO. 14

DEPTH OF TRANSDUCERS = 40 ft.

S. No.	Frequency in KHZ	E-8		F-33	
		Percentage CV	20 log CV in dB	Percentage CV	20 log CV in dB
1	20	3.6	-28.9	1.1	-39.3
2	30	1.4	-36.9	0.8	-41.8
3	40	1.1	-39.1	0.8	-42.3
4	50	0.7	-43.3	0.8	-42.3
5	60	0.9	-41.2	-.7	-43.3
6	70	1.1	-39.3	1.2	-38.6
7	80	1.7	-35.6	0.9	-40.6
8	90	2.0	-33.9	1.3	-38.1

TABLE NO. 15

DEPTH OF TRANSDUCERS = 20 ft.

S. No.	Frequency in KHZ	E-8		F-33	
		Percentage CV	20 log CV	Percentage CV	20 log CV
1	20	2.8	-30.9	1.7	-35.2
2	30	3.3	-29.5	1.8	-34.9
3	40	3.3	-29.7	1.4	-37.2
4	50	1.5	-36.3	1.4	-37.2
5	60	2.1	-33.7	1.1	-38.9
6	70	2.1	-33.7	0.8	-41.7
7	80	2.3	-32.9	1.2	-38.6
8	90	1.1	-39.6	1.6	-36.0

TABLE NO. 16

DEPTH OF TRANSDUCERS = 10 ft.

S. No.	Frequency in KHZ	E-8		F-33	
		Percentage CV	20 log CV	Percentage CV	20 log CV
1	20	2.8	-31.2	5.5	-25.1
2	30	1.1	-38.8	15.0	-16.4
3	40	13.0	-17.7	32.8	- 9.7
4	50	2.2	-33.2	-	-
5	60	10.8	-19.3	23.0	-12.7
6	70	-	-	-	-
7	80	-	-	-	-
8	90	2.8	-30.9	6.5	-23.7

V. SUMMARY

The parametric system designed was adequate for low power applications. The secondary frequency for optimum operation was 60 KHZ and amplitude modulation was found to be the best mode of modulation. Free field measurements of the radiation pattern showed the typical absence of side lobes in the difference frequency beam. 6 dB bandwidth of 60 KHZ difference frequency was found to be 5.8^{o}. The maximum Sound Pressure Level at 100 cms. was found to be 46.2 dB re 1 microbar.

The reflection of the beam by a calm water-air surface caused severe broadening of the beam and the reduction of the sound pressure level at the difference frequency as compared with the direct path signal from source to hydrophone. The beam disruption is attributed to the phase reversal that occurs upon reflection and the results are consistent with results presented by Mellenbruch and Muir at the 86th meeting of the Acoustical Society of America. (Nov. 1973).

The coefficient of variation was found to be less than 3% at the depths of 20 ft. and 40 ft. For these depths, the coefficient of variation was higher for the parametric beam as compared to that of a conventional sound beam. It was, however, noticed that the coefficient of variation was much higher near the surface of sea water, the maximum value

being 30% at 10 ft. of depth. The parametric beam seems to have lower coefficient of variation as compared to that of a conventional beam at the depth of 10 ft.

The present parametric system was not adequate for secondary frequencies of less than 40 KHZ.

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Parametric Acoustic Source
Reflection of parametric beam from water-air interface
Amplitude Coefficient of variation of the parametric transmission

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Parametric sound generation has been an active area of applied research for the last ten years. The acoustic parametric source takes advantage of the non-linearity of the medium to generate energy at the difference of two high frequencies. The principal advantage of a parametric source over a conventional transducer is its high resolution capability. The characteristic is a result of its narrow beam width (with no attendant side lobes) and

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20. ABSTRACT (contd.)

broad bandwidth.

The parametric source was designed and tested in the laboratory and also at sea. Laboratory studies showed severe broadening of the parametric beam and reduction of difference-tone pressure on reflection from a smooth air-water surface. This is attributed to the phase reversal that occurs on reflection.

The coefficient of amplitude variation at sea was found to be less than 3% at the depth of 20 and 40 ft. and was much higher at 10 ft. depth. The coefficient of amplitude variation was higher for the parametric beam as compared to that of a conventional sound beam at the depths of 20 and 40 ft. The parametric beam had lower coefficient of variation as compared to that of a conventional beam at the depth of 10 ft.

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K3964 Khosla
c.1 Design and application
of an underwater acoustic
parametric source.